LONDON-WEST MIDLANDS ENVIRONMENTAL STATEMENT

Volume 5 | Technical Appendices

CFA13 | Calvert, Steeple Claydon, Twyford and Chetwode

Padbury Brook modelling report (WR-004-004)

Water resources

November 2013

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1 Introduction

1.1 Structure of the water resources and flood risk assessment appendices

1.1.1 The water resources and flood risk assessment appendices comprise four parts. The first of these is a route-wide appendix (Volume 5: Appendix WR-001-000).

1.1.2 Specific appendices for each community forum area (CFA) are also provided. For the Calvert, Steeple Claydon, Twyford and Chetwode area (CFA13) these are:

- a water resources assessment (Volume 5: Appendix WR-002-013);
- a flood risk assessment (Volume 5: Appendix WR-003-013); and
- a hydraulic modelling report for the Padbury Brook at Twyford and Godington (i.e. this appendix)

1.1.3 Maps referred to throughout the water resources and flood risk assessment appendices are contained in the Volume 5, Water Resources and Flood Risk Assessment Map Book.

1.2 Scope and structure of this assessment

1.2.1 This document presents an assessment of the fluvial flood risk of the Padbury Brook at Twyford and Godington, for the existing (baseline) and post-development (Proposed Scheme) scenarios. A two-dimensional TUFLOW model has been developed in order to investigate the impact of the proposed piers within the floodplain and advise the flood risk assessment.

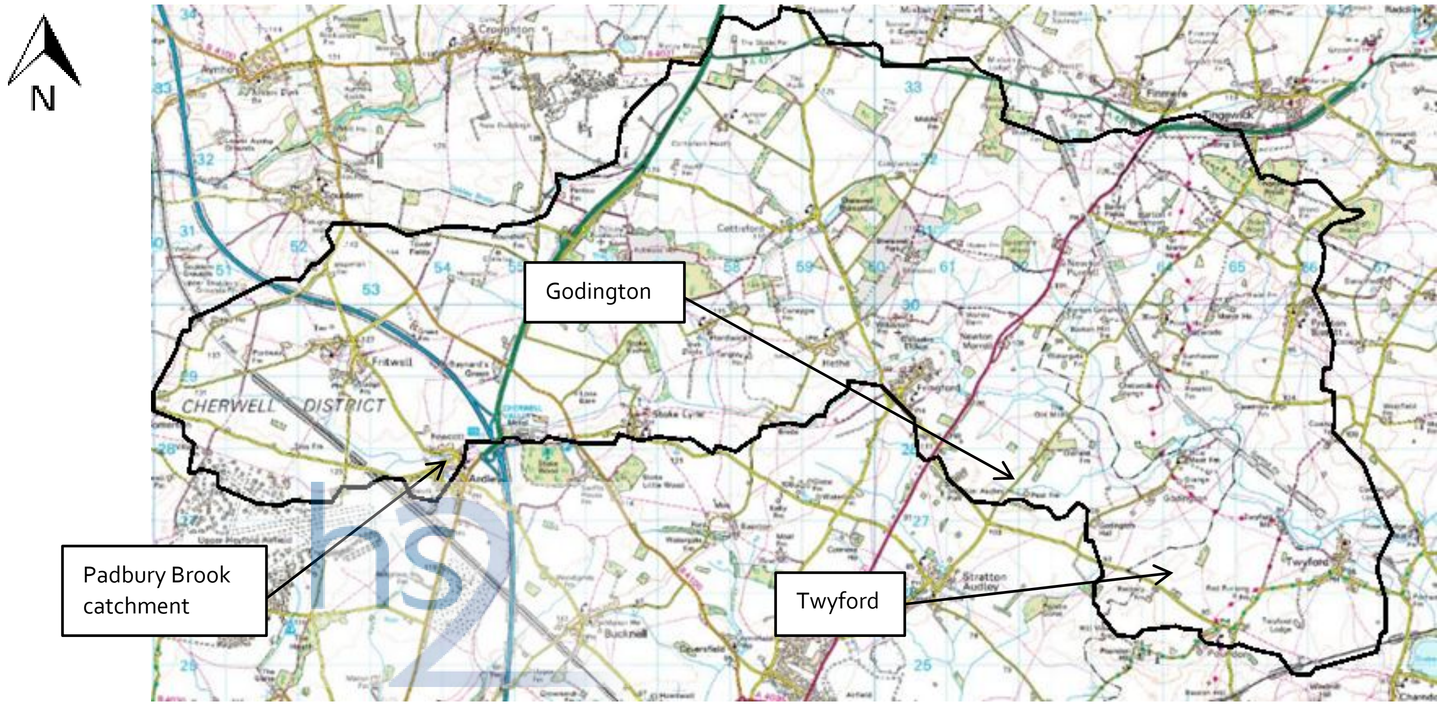
1.2.2 The catchment hydrology is reported in Section 2. Flood water levels, depths and floodplain extents are reported for the baseline (Section 3) and scheme scenarios (Section 4). Section 5 includes conclusions and recommendations and Section 6 covers assumptions and limitations of the hydrology and hydraulic modelling.

2 Hydrology

2.1 Location plan and topography

2.1.1 The study catchment is within the rural upper reaches of the Padbury Brook, a tributary to the River Great Ouse. The study area covers the reach of the Padbury Brook between Godington and Twyford (as shown in Figure 1) approximately 12km upstream of its confluence with the River Great Ouse east of Buckingham. The Padbury Brook is locally termed 'the Twins' since two parallel channels meander through this reach of the catchment. The watercourse is complex through the study area with multiple catchments joining the main channels and significant physical modification to channels. The downstream boundary of the study catchment has been chosen at Three Bridge Mill to the north-east of Twyford.

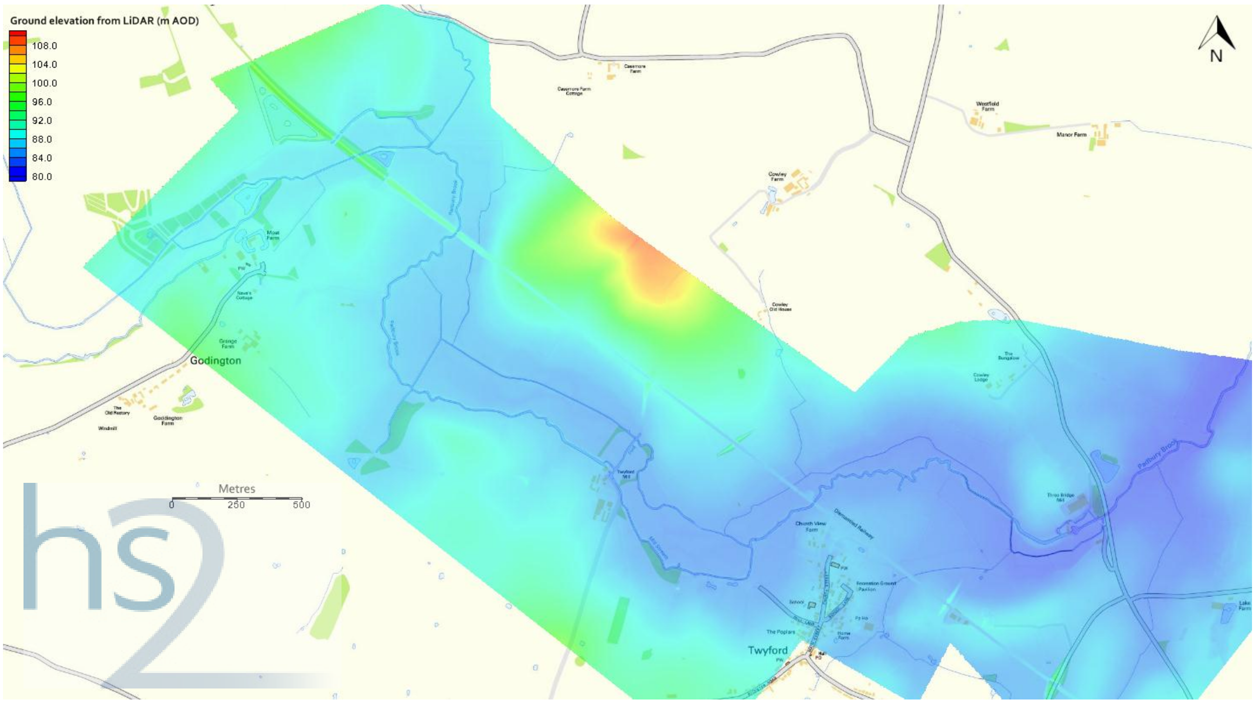
Figure 1: Location and extent of the Padbury Brook catchment



2.1.2 The catchment of the Padbury Brook within the study area contains a number of small villages, including Twyford, Godington, Preston Bissett, Newton Purcell, Barton Hartshorn, Fringford, Hethe, Stoke Lyne, Ardley and Fritwell. The topography of the catchment is flat along the wide, meandering river basin. Ground levels within the study area range from approximately 80-90m above Ordnance Datum (AOD) along the river basin to in excess of 100m AOD on the surrounding high ground.

2.1.3 Figure 2 uses light detection and ranging (LiDAR) information to illustrate the topography of the Padbury Brook valley at Godington and Twyford.

Figure 2: Topography of the Padbury Brook catchment



2.2 Hydrological context

2.2.1 The Padbury Brook has a catchment size of 79.2km^2 at Three Bridge Mill downstream of the crossing of the Proposed Scheme at Twyford. The catchment is shallow (index of catchment steepness (DSPBAR) = 18.6) which is unsurprising given the nature of the wide, flat floodplain. The longest drainage path is 24.1km, with the average at 12.6km, suggesting some variability in catchment width along the length of the valley.

2.2.2 The climate and soils descriptors show that the catchment is relatively dry with low annual rainfall (Standard Average Annual Rainfall (SAAR) = 657) and a low proportion of time annually where soils are 'wet' (index of proportion of time soils are wet (PROPWET) = 0.3). There is a small amount of recorded attenuation due to reservoirs or lakes within the catchment (flood attenuation due to reservoirs and lakes (FARL) = 0.988).

2.2.3 The catchment is 'essentially rural' with an urban extent value (in the year 2000) of 0.009. Urban areas comprise of Newton Purcell, Hethe, Ardley and Fritwell to the west of the study area.

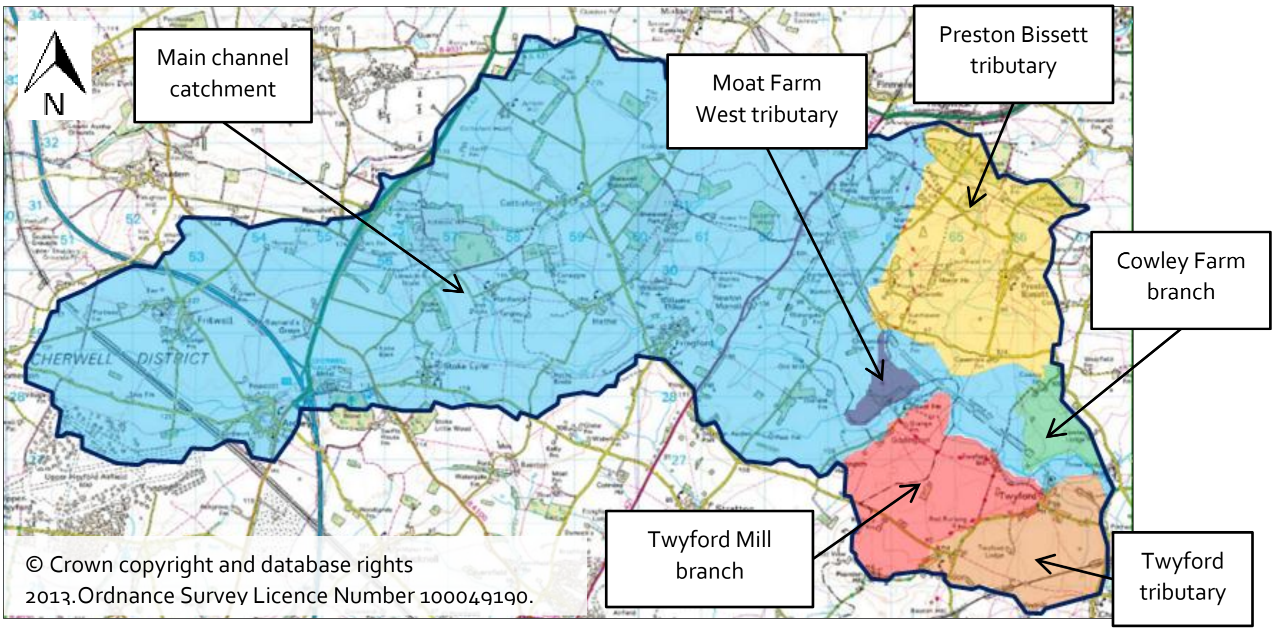
2.2.4 The natural catchment at the location of interest is composed of the primary watercourse (twin channels of the Padbury Brook) and five smaller inflows from tributaries and branches which join the main channels, as shown in Figure 3, that include:

- the main channels of the Padbury Brook in this location comprise two parallel channels which originate from several small catchments joining upstream of the study area. The main channel originates from east of Fewcott and Ardley

with major branches joining at Stoke Lyne from Hethe and from Newton Purcell and Barton Hartshorn before it reaches Godington. The combined area of these catchments, which form the main channels for the purposes of this model, is approximately 60.3km^2 (shaded in blue in Figure 3);

- a small branch located to the west of Moat Farm joins the main catchment as a parallel channel just downstream of Godington. This small catchment is approximately 0.6km^2 and is termed 'Moat Farm West' tributary for the purpose of this report (shaded in purple in Figure 3);
- a large tributary joins from the northern side close to Godington between the two crossings of the Padbury Brook by the Proposed Scheme. This tributary consists of three branches which join before its confluence with the Padbury Brook channel. These originate from Chetwode and from the north and south of Preston Bissett. This catchment is approximately 8.3km^2 and has very short drainage paths. It is termed 'Preston Bissett' tributary and is shaded in yellow in Figure 3;
- a catchment close to Twyford Mill between Godington and Twyford joins from the southern side and contributes to the southern-most parallel channel. This catchment is approximately 5km^2 and referred to as 'Twyford Mill' branch (shaded in red in Figure 3);
- a small tributary which originates in agricultural land close to Cowley Farm joins the western-most of the two main channels. This contributing area is approximately 1.3km^2 and is shaded green in Figure 3. This is termed 'Cowley Farm' branch for the purposes of this report; and
- a tributary originating east of Twyford joins the main channels of the Padbury Brook immediately upstream of the southern extent of the study area close to Three Bridge Mill. This tributary is crossed by the Proposed Scheme. It is 3.8km^2 in area and is shown in orange in Figure 3. It is referred to as 'Twyford tributary' throughout the Proposed Scheme and within this modelling report.

Figure 3: Padbury Brook catchment overview map



2.2.5 The catchments of the lateral inflows have been checked to ensure that their combined area corresponds to the total catchment area at the downstream boundary at Three Bridge Mill.

2.3 Hydrological assessment

2.3.1 An initial hydrological assessment was undertaken for the entire Padbury Brook catchment to the downstream boundary taken just upstream of Three Bridge Mill east of Twyford to determine the likely peak flows within the watercourse. A full routed rainfall-runoff output, such as that derived using the Revitalised Flood Hydrograph method (ReFH) is required for time-varying hydrodynamic modelling. Scaling was used to add an uplift of 20% to the 100 year return period to account for climate change.

Revitalised Flood Hydrograph rainfall runoff method

2.3.2 The ReFH method was applied using the spreadsheet implementation (v1.4) provided by HR Wallingford together with the catchment descriptors obtained from the Flood Estimation Handbook (FEH) CD-ROM (v3). No rainfall or flow data was available for the catchment and all ReFH design standard parameters were therefore applied without observed or analogue adjustments. A model timestep of one hour and storm duration of 17 hours was used in the analysis.

2.3.3 The FEH depth-duration-frequency rainfall modelling for the catchment was used to obtain total rainfall volumes for each design storm which was spread across the chosen storm duration using the winter storm profile due to the rural nature of the catchment. Seasonal correction and areal reduction factors of 0.70 and 0.94 respectively were applied with resultant total and peak storm rainfall as shown in Table 1.

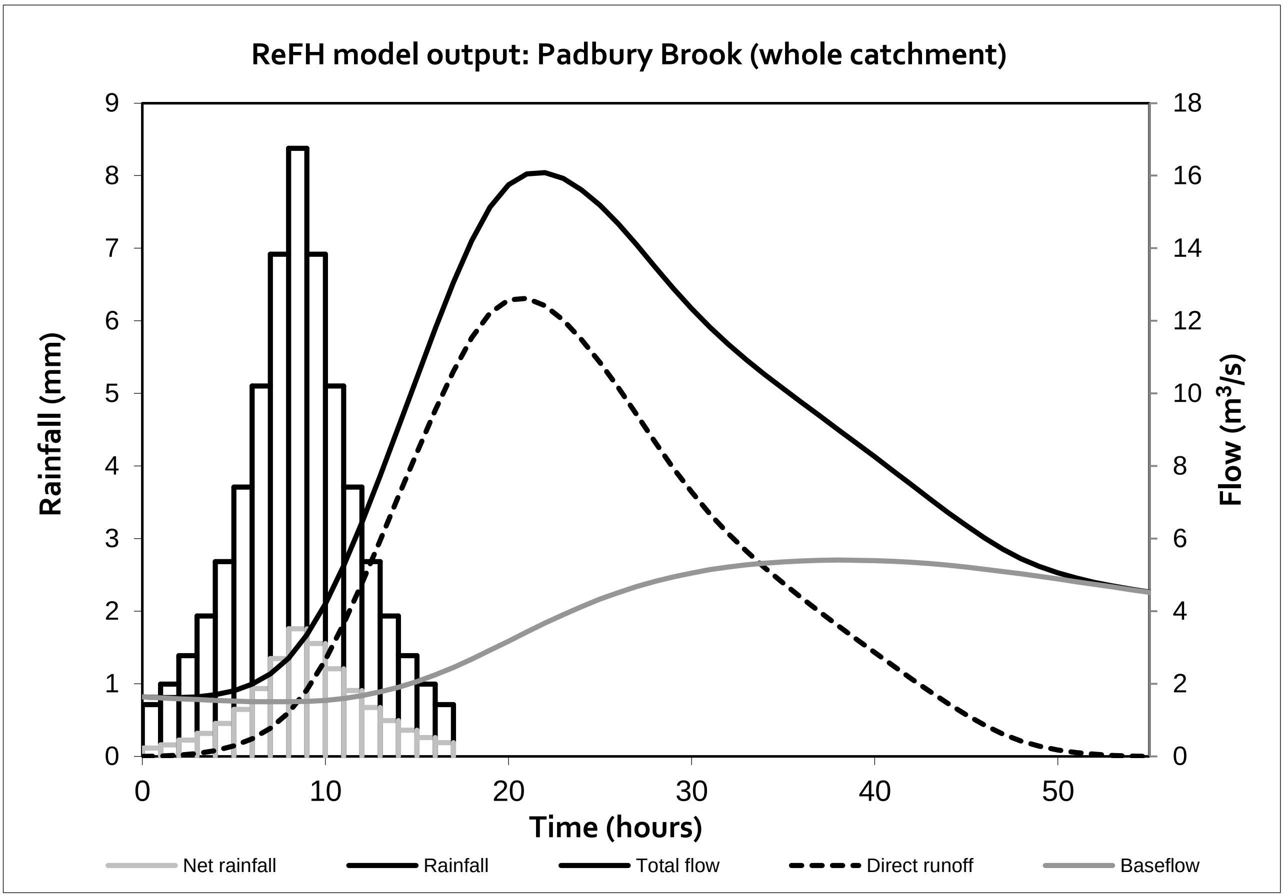
2.3.4 The loss, routing and baseflow models use the catchment descriptors and standard ReFH models and parameters in the absence of any gauged flow information for the watercourse. The unit hydrograph time to peak is 22 hours which is reasonable for a catchment of this size. Calculated initial baseflows are reasonably low at approximately 1.6m^3/s. An initial soil moisture deficit of 96mm was calculated. The combined models were applied to the calculated input rainfall by scaling and aggregating the unit hydrograph calculated using the loss and routing models. The baseflow hydrograph was then combined with the storm hydrograph to give a design hydrograph for each return period.

Table 1: Padbury Brook (catchment at Three Bridge Mill) ReFH rainfall volumes and peak flows

Return period	Depth-duration-frequency rainfall (mm)	Design rainfall (mm)	Peak rainfall (mm)	Peak runoff (m^3/s)
20 years	58.3	38.1	5.8	11.6
100 years	84.5	55.3	8.4	16.1
1000 years	143.0	93.5	14.2	28.1

2.3.5 The 100 year return period rainfall event results in a peak runoff rate of 16.1m^3/s. The rainfall hyetograph, showing distribution of rainfall over time, and corresponding fluvial flood hydrograph are presented in Figure 4.

Figure 4: Padbury Brook (whole catchment) ReFH hydrograph for the 100 year return period event



Modelled sub-catchment inflows

2.3.6 Due to the fact there is a main channel and five separate inflows into the Padbury Brook within the study area (as described in Section 2.2 of this report) each sub-catchment inflow must be applied separately at the relevant boundary inflow location in order to accurately model the watercourse and avoid 'double counting' the tributaries. Consequently, it is necessary to divide the catchment into the component parts to obtain each separate inflow.

2.3.7 The catchment descriptors for the sub-catchment were extracted by subtracting component parts from the whole catchment. Area-weighted averages, or specific adjustment procedures as detailed in Volume 5 of the FEH[1], were used to create a catchment descriptor file for the main channel only by removing the tributaries as presented in Table 2.

2.3.8 The sub-catchment inflows from each tributary were subtracted one at a time from the total catchment in order to derive a 'main channel' catchment. ReFH flows were calculated for each catchment and the modified main channel catchment descriptor file, and were applied to the hydraulic model at the relevant boundary locations.

[1] Institute of Hydrology (1999), *Flood Estimation Handbook.*

Table 2: Key model catchment descriptors for the Padbury Brook and its sub-catchments

Model catchment descriptors	Padbury Brook (direct, whole catchment)	Moat Farm west tributary (direct)	Preston Bissett tributary (direct)	Twyford Mill branch (direct)	Cowley Farm branch (direct)	Twyford tributary (direct)	Padbury Brook main channels only (derived)
AREA	79.21	0.63	8.29	4.98	1.29	3.76	60.26
BFIHOST	0.64	0.43	0.32	0.29	0.33	0.25	0.75
DPLBAR	12.57	0.85	2.78	2.63	1.41	2.21	9.45
DPSBAR	18.6	15.0	20.0	16.1	20.6	13.5	18.8
FARL	0.99	1.00	1.00	1.00	1.00	1.00	1.00
FPEXT	0.13	0.39	0.10	0.22	0.15	0.23	0.12
FPDBAR	0.78	2.67	0.67	1.02	1.01	1.18	0.72
PROPWET	0.32	0.32	0.32	0.32	0.32	0.32	0.32
SAAR	657	661	647	626	637	617	664
SPRHOST	27.27	43.48	44.02	49.62	45.83	51.54	21.04
URBEXT2000	0.01	0.00	0.01	0.01	0.00	0.00	0.01

2.3.9 Modelled inflows were calculated using the ReFH for each catchment for a number of return periods, as presented in Table 3. In order to account for climate change, an uplift of 20% was applied to peak 100 year return period flow.

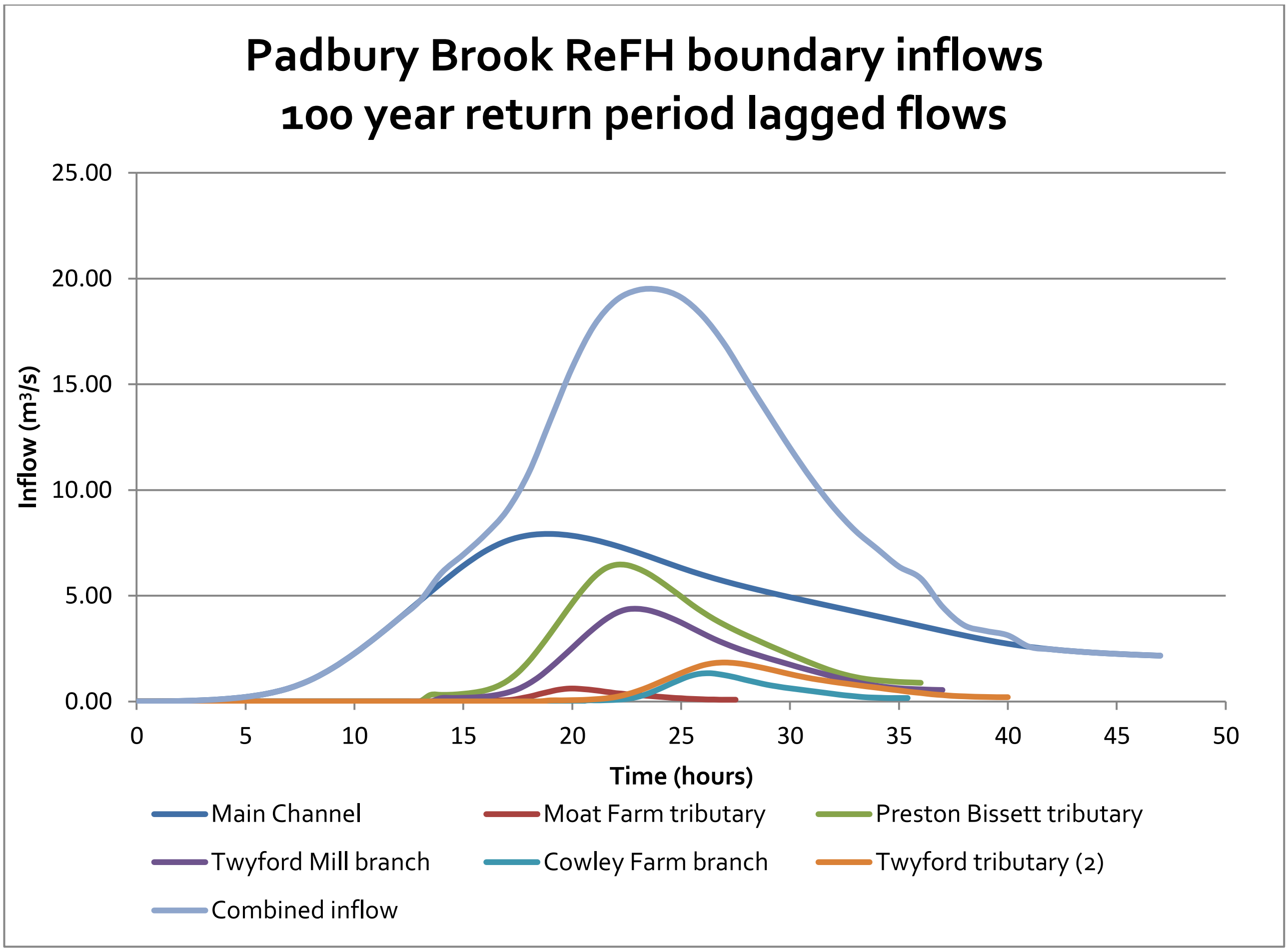
Table 3: Padbury Brook modelled ReFH inflows (m^3/s)

Return period	ReFH inflows (m^3/s)					
	Padbury Brook (main channels)	Moat Farm west tributary	Preston Bissett tributary	Twyford Mill branch	Cowley Farm branch	Twyford tributary
20 years	5.3	0.2	4.6	3.1	0.9	2.5
100 years	7.9	0.6	6.5	4.4	1.3	3.7
100 years + 20%	9.5	0.7	7.8	5.2	1.6	4.4
1000 years	15.6	1.1	11.3	7.9	2.4	6.8

2.3.10 The five sub-catchments are relatively small and are typically steeper than the large, flat river basin catchment. These catchments have faster response times than the flow through the Padbury Brook main channels and therefore shorter modelled critical storm durations. In order to obtain the 'worst-case' scenario within the study area the

peak flow was lagged in order to coincide with the peak of the main channel flow. Since the model covers a large area the peak flow is at different times for different areas. A test run of the hydraulic model was undertaken using only the main channel flow in order to obtain the peak flow times closest to the inflow locations of the tributaries. The five sub-catchments were then lagged accordingly for the sub-catchment peak to coincide with the passing peak flow within the main channel at the confluence location as illustrated in Figure 5.

Figure 5: Padbury Brook staggered lagged ReFH inflows for the 100 year design rainfall



2.3.11 The Twyford tributary originates from two equal sub-catchments to the east of Twyford. These are individually too small to be identified by the FEH CD-ROM as separate catchments and therefore the ReFH flow has been calculated downstream of the confluence of the two branches. In order to apply these to the two separate channels at the edge of the study area the calculated flow was divided by two and 50% of the total was applied at each branch.

2.3.12 The combined peak inflow for the 100 year return period, when taking into account the lagged sub-catchments was found to be approximately 19.5 m^3/s. This is larger than the modelled total catchment peak and indicates the conservative approach. Results of the initial 100 year TUFLOW run confirm a peak flow into the

two-dimensional domain of 19.2m^3/s at 23.50 hours and a peak flow out of the model of 18.9m^3/s at 28.47 hours.

3 Baseline hydraulic modelling

3.1 Model definition

3.1.1 A hydraulic model has been constructed using SMS-TUFLOW. The model utilised the two-dimensional capabilities of TUFLOW (Version 2012-05-AE, iDP, w32), and the convenience of the Aquaveo SMS (Version 11.0) front end for visualisation purposes.

3.1.2 The Padbury Brook floodplain in this location is wide and very flat with complex overland flow patterns as a result of the tributaries and branches, parallel channels and structures within the floodplain. The Proposed Scheme will add barriers within the floodplain, in the form of embankments and culverts and therefore a two-dimensional model was necessary in order to accurately represent the overland flow patterns. Given the nature of the modelling exercise and lack of topographic survey an imbedded one-dimensional channel was not added to the model. Culverts and bridge structures beneath the former Great Central Main Line were represented in the modelling using one-dimensional ESTRY elements. A two-dimensional flow constriction unit was used to represent the arched road bridge beneath Perry Hill adjacent to Three Bridge Mill.

3.1.3 The topography of the model is based upon 2m resolution LiDAR. A uniform 5m TUFLOW grid was used, since this was considered appropriate given the size and scale of the model. No modifications have been made to the cell resolution or base LiDAR.

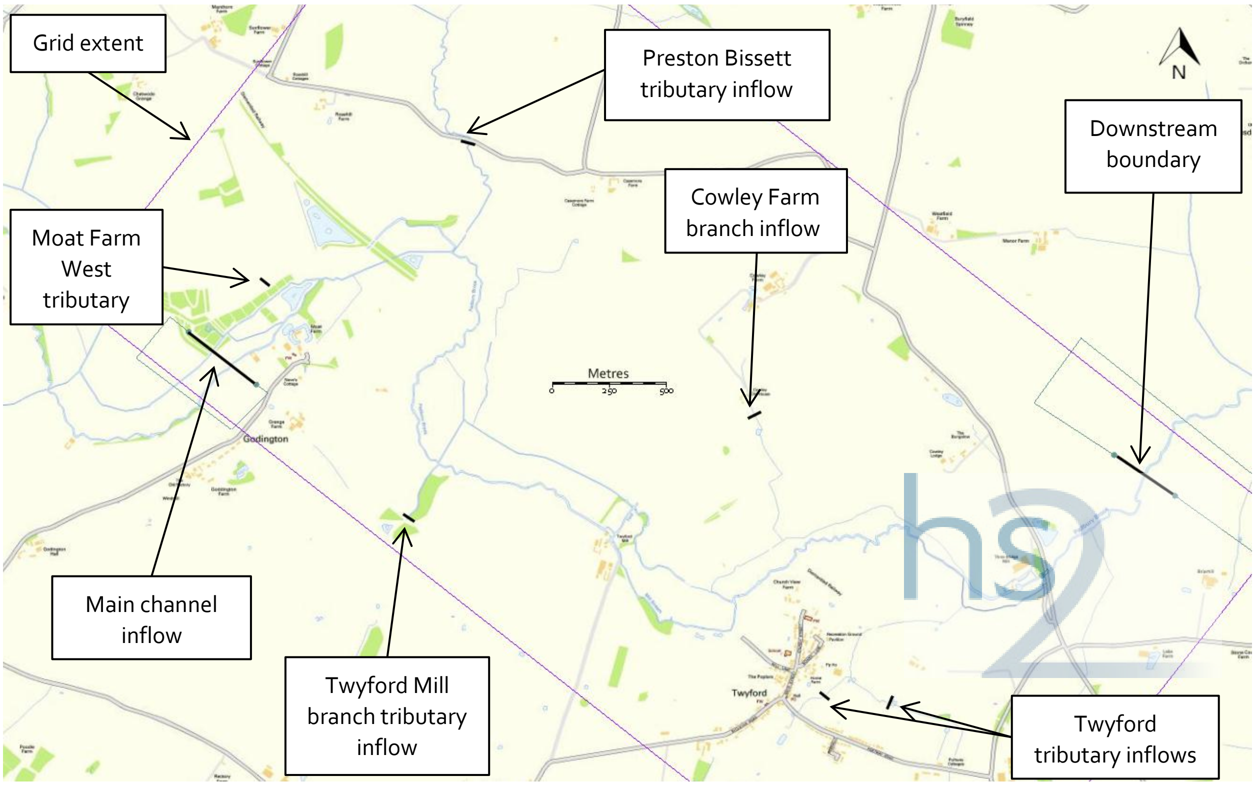
3.2 Model boundaries

3.2.1 The extent of the TUFLOW model and placement of selected boundaries and inflows in relation to Twyford and Godington is shown in Figure 6.

3.2.2 The upstream boundary of the main channels of the Padbury Brook has been defined as a flow-time boundary. The five tributaries were also added as flow-time boundaries positioned at various locations along the length of the main channels. Corresponding calculated ReFH methodology hydrographs were applied to each inflow.

3.2.3 A flow-head boundary has been applied to the downstream extent of the model and has been automatically generated by TUFLOW based on an assumed gradient of 0.001. The downstream boundary has been located downstream of Perry Hill in order to ensure that any influence associated with the road bridge is represented within the model.

Figure 6: Overview of the Padbury Brook model at Twyford and Godington



3.3 Roughness coefficients and structural definitions

3.3.1 The whole two-dimensional domain has been classified as 'grassland' and assigned a Manning's roughness value of 0.035. This ensures the floodplain is represented as grass. This was chosen from a normal value for pasture floodplain in accordance with Chow (1959)[2]. Since this is an impact assessment, roughness values at the lower end of what is deemed reasonable and appropriate were chosen in order to produce the largest relative impact.

3.3.2 Ordnance Survey (OS) Mastermap layers were imported into SMS in order to define different land uses and further detail has been added to refine Manning's roughness values. The roughness values applied are listed in Table 4.

[2] Ven Te Chow (1959, 2009 edition). *Open-channel hydraulics*, The Blackburn Press, Caldwell, NJ, USA.

Table 4: Manning's roughness values

Material type	Manning's roughness value
Grassland	0.035
Water surface	0.040
Roads	0.020
Paved	0.020
Tracks	0.033
Scrub	0.050
Verges	0.050
Trees	0.100
Structures	0.050
Buildings	1.000

3.3.3 The former Great Central Main Line embankment is present throughout the study area. The LiDAR digital terrain model (DTM) illustrates that this embankment is raised above the surrounding floodplain. The elevation of this disused embankment rises from east to west through the study area from approximately 84m AOD east of Twyford to approximately 100m AOD at Godington. The Padbury Brook main channels pass under this embankment once at Twyford and twice at Godington. The Twyford tributary is also crossed east of Twyford village.

3.3.4 The embankment and associated bridge structures and culverts influence out-of-bank flow mechanics in the area and therefore it is important to represent these within the model. These were modelled using one-dimensional ESTRY units embedded within the TUFLOW mesh. This method was used since the structures are typically smaller than the two-dimensional grid cell size.

3.3.5 The main channels are spanned by bridge structures, two at the western Godington crossing, one at the eastern Godington crossing and two at Twyford. Site access was limited and no topographic survey was available at the time of model build. Best estimates of the size and shape of these structures were made from a walkover survey (where permitted), LiDAR and aerial photography. These are included in the model as 5m by 5m box culvert structures.

3.3.6 Two smaller watercourses pass under the embankment; one parallel to the southern crossing at Godington and another to convey the tributary east of Twyford. These are included as 1.2m diameter circular culverts.

3.3.7 A two-dimensional flow construction unit was included within the model to represent the bridge beneath Perry Hill adjacent to Three Bridge Mill. No topographic survey of this structure was available, and therefore an estimate of the size and shape of this structure was made from LiDAR and aerial photography. This is included within the model as a 10m wide, 2.5m high box culvert.

3.4 Baseline model results

Flooding mechanisms

3.4.1 Flow enters the modelled area close to Moat Farm through two parallel channels which join upstream of the former Great Central Main Line embankment. Flows quickly overtop the banks during larger return period events and the embankment poses a restriction to flood flows. Flow from a small catchment to the west of Moat Farm initially remains in-channel beneath the western-most underbridge, however, once the channel is overtopped, spills over the right bank and down the right bank floodplain to join the main flow in the area upstream of the embankment.

3.4.2 Downstream of the embankment, between the two Godington crossings, flood flows follow the route of the channel before spilling onto the wide floodplain. A tributary from Preston Bissett joins between the two crossings. This tributary provides significant flows considering its size due to the nature of the short drainage paths within the catchment. This adds significant flow to the main channel which is unable to pass beneath the southern Godington underbridge crossing and floodwater is held behind the embankment. This creates a very wide, deep floodplain inundation on the north-eastern side of the disused railway embankment.

3.4.3 Downstream of the Godington south crossing the Padbury Brook flows in two parallel channels downstream past Twyford Mill. The larger of the two channels is an artificially raised mill stream which is significantly higher (approximately 1m) than the secondary channel. Although the mill stream is the predominant route for in-channel flow once overtopped the lower, secondary channel and associated floodplain forms the major flow route. A tributary from a branch on the southern side close to Twyford Mill joins the larger, raised channel, quickly overtopping and flowing down gradient to contribute to the major flood flows in the area. The two channels interact multiple times upstream of the Twyford crossing location, however, predominantly flow is out-of-bank overland down the lowest land courses.

3.4.4 The two parallel channels pass under the former Great Central Main Line embankment at Twyford with the western underbridge passing the major portion of the flow. The embankment forms a restriction to the overland flow within the wide floodplain. Downstream of the crossing, flows continue in two parallel channels with the smaller western channel continuing to form the major flow route. The raised mill stream passes in-channel flow; however the major out-of-bank flow is on the left-bank of this channel. Flow on the right-bank side spills from the raised channel just downstream of the underbridge crossing and flows in the low area of floodplain on the right-hand side of the raised channel. A tributary enters the western branch of the parallel channels.

3.4.5 The tributary from Twyford originates from two similar sized branches near Twyford village which combine before passing under the former Great Central Main Line in a small, brick culvert (1.2m diameter circular cross section). The raised embankment poses a restriction to out-of-bank flows which cannot pass adequately through the culvert. This embankment elevation is lowest at this end of the study area and is therefore eventually overtopped by flow from the Twyford tributary. Downstream of the embankment the tributary combines with the main flow in the Padbury Brook

flowing overland to towards Three Bridge Mill. Flow passes beneath the road at Perry Hill, continuing to the north-east towards the downstream boundary.

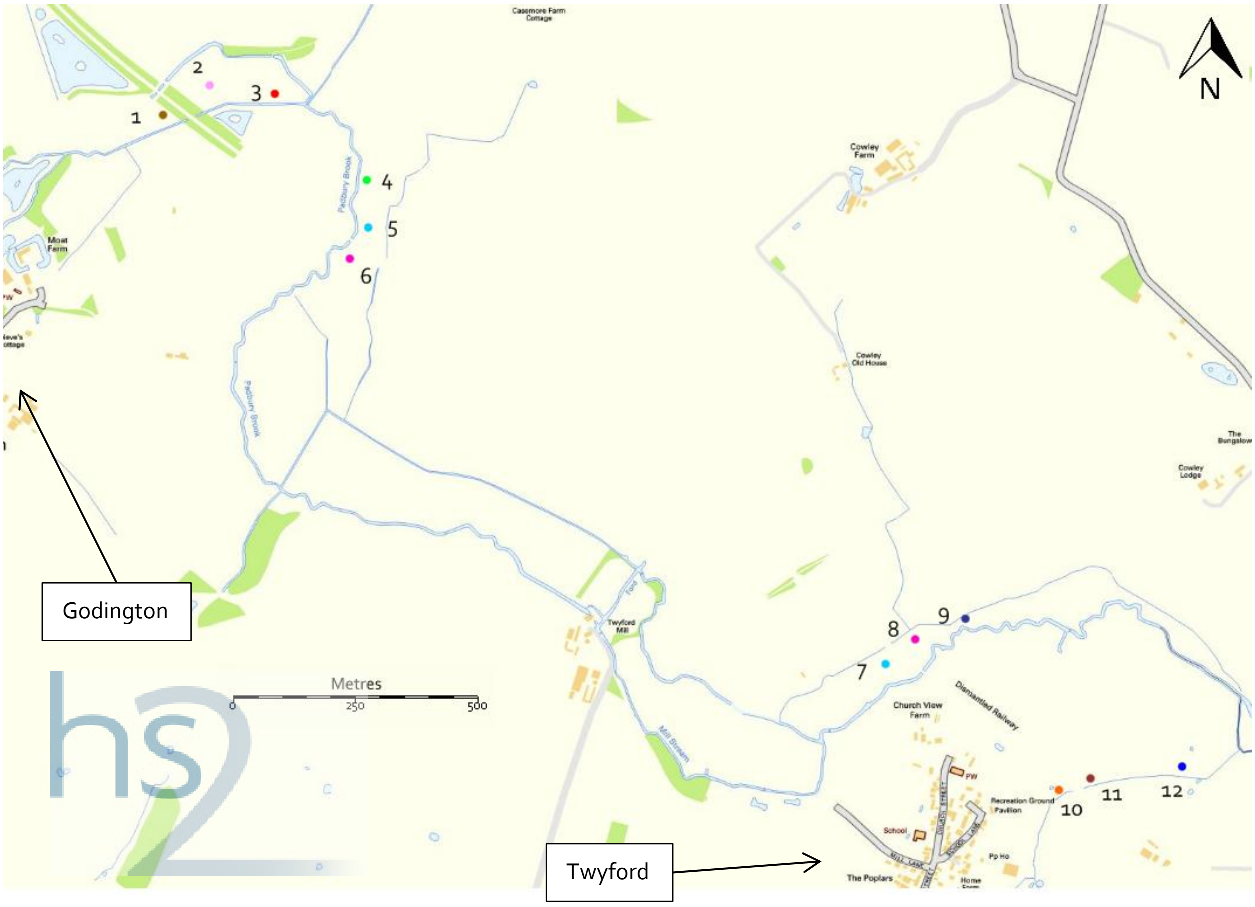
Flood depths and levels

3.4.6 Modelled flood water levels and depths were extracted from chosen points. Additionally, model flows were checked at various locations to ensure that the flow was realistic across the grid and through the one-dimensional ESTRY elements.

3.4.7 Observation points were selected to represent results at a range of locations and used to extract data for all return periods tested in both the existing and scheme scenarios. For each of the four main crossing locations, results were selected upstream of the first embankment (either the former Great Central Main Line embankment or Proposed Scheme), between the existing and proposed embankments, and downstream of the second embankment.

3.4.8 Observation point locations can be seen in Figure 7. Observation points one, two and three illustrate results at Godington west, representing the upstream, between and downstream locations respectively. Observation points four, five and six record results at Godington east. Observation points seven, eight and nine represent the Twyford main crossing. Observation points 10, 11 and 12 record levels and depths from the Twyford tributary.

Figure 7: Observation points location plan



3.4.9 The maximum modelled baseline flood water levels and depths, extracted from the two-dimensional model for all return periods, are recorded in Table 5. Points are references with descriptions of their location either upstream or downstream of the former Great Central Main Line embankment.

Table 5: Baseline modelled maximum flood water levels and depths

Observation point	Location	Description	Peak 5% annual exceedance probability		Peak 1% annual exceedance probability + climate change		Peak 0.1% annual exceedance probability + climate change	
			Water level (m AOD)	Flood depth (m)	Water level (m AOD)	Flood depth (m)	Water level (m AOD)	Flood depth (m)
1	Godington west crossing	Upstream of former Great Central Main Line	87.14	0.79	87.39	1.05	87.58	1.24
2		Downstream of former Great Central Main Line	86.67	0.45	86.82	0.60	87.26	1.04
3			86.50	0.27	86.80	0.56	87.25	1.02
4	Godington east crossing	Upstream of former Great Central Main Line	86.38	0.74	86.79	1.15	87.25	1.61
5			86.38	0.98	86.79	1.39	87.25	1.86
6		Downstream of former Great Central Main Line	85.36	0.05	85.41	0.10	85.47	0.16
7	Twyford main crossing	Upstream of former Great Central Main Line	83.67	0.90	84.01	1.23	84.36	1.58
8		Downstream of former Great Central Main Line	83.29	0.52	83.38	0.60	83.46	0.68
9			83.07	0.19	83.13	0.26	83.20	0.33
10	Twyford tributary crossing	Upstream of former Great Central Main Line	84.06	0.58	84.43	0.96	84.51	1.03
11		Downstream of former Great Central Main Line	83.38	0.06	83.40	0.08	83.43	0.12
12			82.50	0.07	82.50	0.08	82.55	0.12

3.4.10 Visual illustrations of the flood mechanisms and modelled flood depths for the existing 1 in 100 years return period event (plus uplift of 20% for climate change) can be seen in Figure 8 and Figure 9 for Godington and Twyford respectively.

Figure 8: 100 year plus climate change existing flood depths (m) at Godington

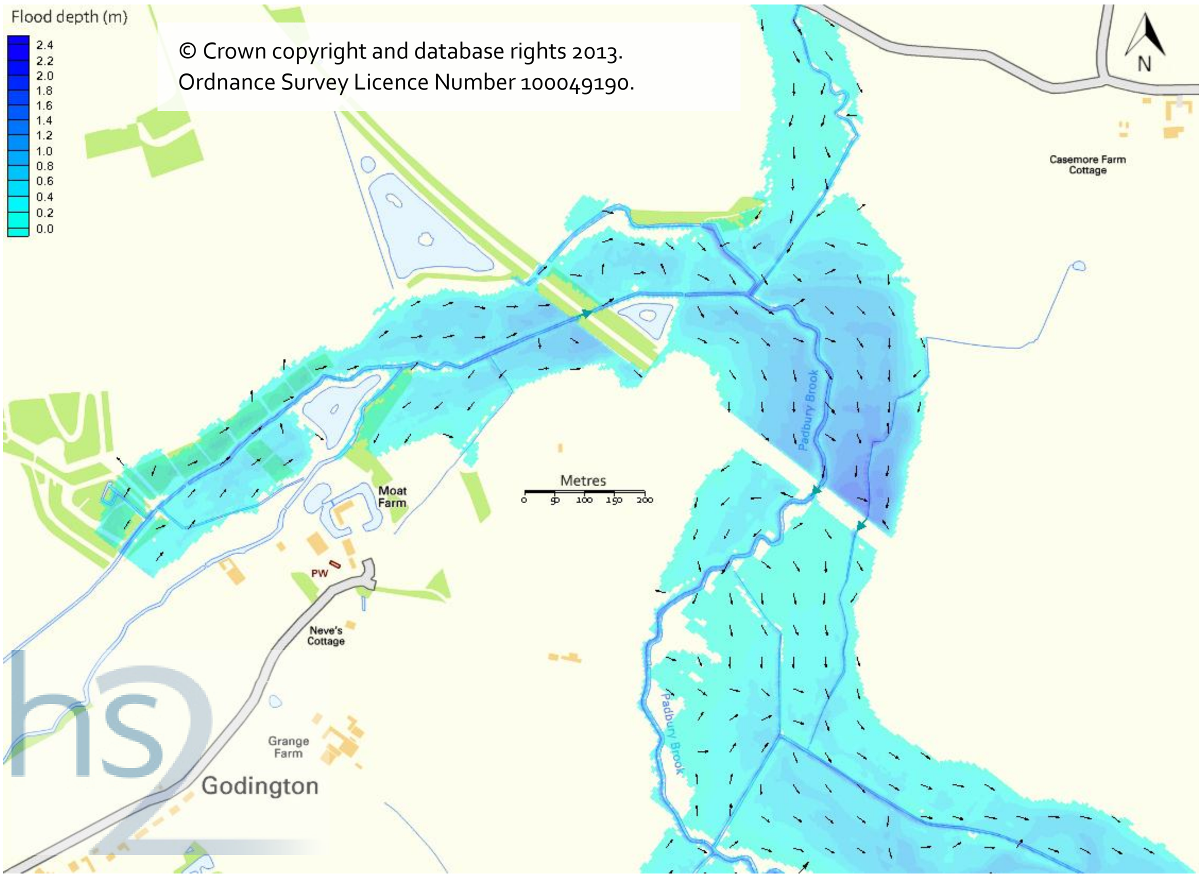
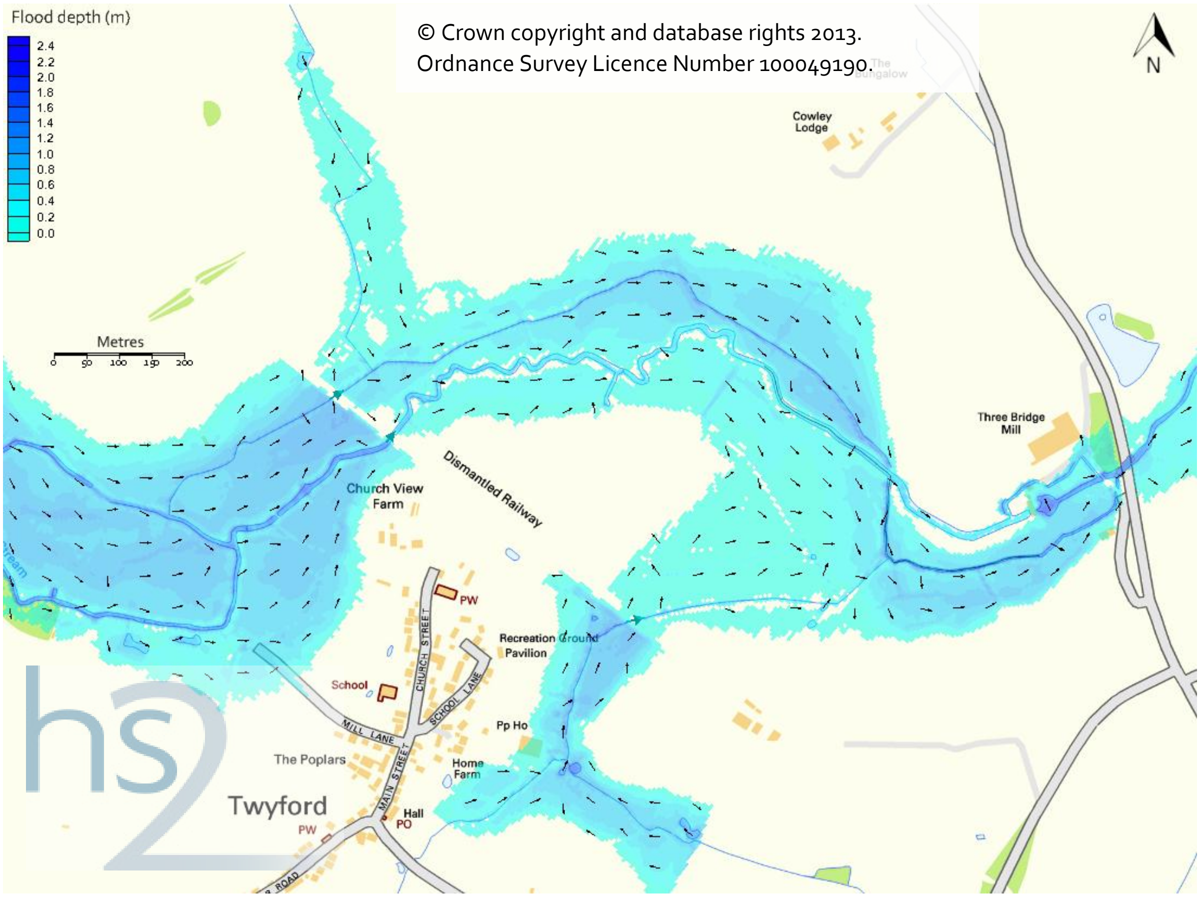


Figure 9: 100 year plus climate change existing flood depths (m) at Twyford



Floodplain extents

3.4.11 Floodplain extents for the 100 year plus climate change and 20 year baseline scenarios are shown in WR-05-30 and WR-06-30 respectively (Volume 5, Water Resources and Flood Risk Map Book).

Flood velocities

3.4.12 Modelled flood velocities are generally very low within the floodplain and considerably higher within the channel. Velocities are on average approximately 0.2m/s in the wide, flat floodplain. Within the channels flow velocities are shown to reach in excess of 1m/s.

Sensitivity testing

3.4.13 In order to verify model results and confirm choices made within this modelling exercise, sensitivity analysis was undertaken to test to implications of increasing Manning's roughness in the floodplain.

3.4.14 The floodplain in this area consists of almost entirely pasture grassland as shown clearly on the OS mapping. A 'normal' roughness value for pasture with high grass of 0.035 was chosen based upon Chow (1959). A walkover survey was undertaken for this study area and based upon this and on aerial photography this value appears to be a reasonable estimation for the grass floodplain.

3.4.15 The model was tested by increasing the Manning's roughness values within the floodplain. Grassland was increased to 0.07 which represents the 'maximum' limit for floodplain with scattered brush and heavy weeds. Other roughness values (trees, roads, buildings and the water surface) were not altered since these are less important than the floodplain in this scenario and generally subject to less variation throughout the year.

3.4.16 The 100 year plus climate change existing scenario was run using the higher roughness floodplain values. Increasing the roughness caused some instability issues due to the flat nature of the downstream boundary and therefore this was steepened. This alteration does not have any impact on the area of interest.

3.4.17 Increasing the floodplain roughness causes an increase in flood water level across the study area, which ranges from approximately 10mm to 110mm. The largest increases in water level are shown downstream of the former Great Central Main Line embankment and culverts where flood depths are shallower and velocities are greater as a result of the obstruction within the floodplain.

3.4.18 The purpose of this modelling exercise was to test the impact of the Proposed Scheme on flood water levels as a result of the placement of embankments and piers within the floodplain, not to define existing baseline flood water levels. The impact of the increased roughness can be tested on the Proposed Scheme modelling in order to compare the impact between the existing and proposed results using both rough and smooth floodplains.

3.4.19 In addition to the sensitivity testing of Manning's roughness within the floodplain the implications of changing the water surface slope and location of the downstream

boundary were tested. Alterations to the downstream boundary were shown to affect levels only immediately upstream of the boundary and these effects did not reach the area of interest. The boundary was therefore deemed sufficiently downstream of the Proposed Scheme.

3.4.20 Visual inspections of the results were carried out for all simulated return periods to ensure that the results looked to be appropriate.

4 Scheme scenario

4.1 Scheme modelling methodology

Hydraulic modelling

4.1.1 The purpose of this modelling exercise is to assess the impact of the Proposed Scheme on flood water levels in the vicinity of Godington and Twyford. The Proposed Scheme crosses the floodplain of the Padbury Brook on embankment with viaducts spanning the channels and culverts conveying the small tributaries.

4.1.2 The Proposed Scheme includes two 75m span structures at Godington west and Godington east and a single 60m span viaduct at Twyford. The narrow opening, relative to the width of the baseline floodplain, will cause restriction of flood flows and will alter flood mechanisms up and downstream of each structure. The tributary east of Twyford will be conveyed beneath the embankment within a 2.1m box culvert. At Godington east, the land drain crossing will be conveyed within a 1.8m culvert and the parallel channel at Godington west within a 2.1m box culvert.

4.1.3 The embankment structure has been modelled by mapping the footprint of the embankment toe along with any noise mitigation and landscaping bunds. These are modelled as Z-lines which are raised to an elevation of 92m AOD which is sufficiently above the floodplain.

4.1.4 Viaducts have been modelled as openings within the embankment and therefore ground levels beneath these remain as per the baseline. Piers are represented by elevating these out of the floodplain. Small culverts beneath the structure are modelled as one-dimensional elements.

4.2 Proposed Scheme model results

Flood depths and levels

4.2.1 Peak levels and depths have been extracted from the same observation points as before. Changes in afflux as a result of the Proposed Scheme scenario have been included in Table 6.

Table 6: Scheme modelled maximum flood levels, depths and increases in afflux

Observation point	Location	Description	Peak 5% annual exceedance probability			Peak 1% annual exceedance probability + climate change			Peak 0.1% annual exceedance probability + climate change		
			Water level (m AOD)	Flood depth (m)	Increase in afflux (m)	Water level (m AOD)	Flood depth (m)	Increase in afflux (m)	Water level (m AOD)	Flood depth (m)	Increase in afflux (m)
1	Godington west crossing	Upstream of former Great Central Main Line	87.14	0.79	0.00	87.40	1.05	0.00	87.61	1.27	0.03
2		Between existing and proposed	86.71	0.49	0.04	86.88	0.66	0.06	87.30	1.09	0.05
3		Downstream of Proposed Scheme	86.55	0.31	0.05	86.82	0.59	0.02	87.28	1.05	0.03
4	Godington east crossing	Upstream of Proposed Scheme	86.40	0.76	0.02	86.81	1.17	0.02	87.28	1.64	0.02
5		Between existing and proposed	86.38	0.99	0.01	86.80	1.41	0.02	87.27	1.88	0.02
6		Downstream of former Great Central Main Line	85.36	0.05	0.00	85.42	0.11	0.00	85.47	0.17	0.00
7	Twyford main crossing	Upstream of former Great Central Main Line	83.78	1.01	0.11	84.04	1.27	0.03	84.37	1.60	0.01
8		Between existing and proposed	83.46	0.68	0.16	83.56	0.78	0.18	83.68	0.90	0.22
9		Downstream of Proposed Scheme	83.11	0.24	0.05	83.20	0.33	0.07	83.26	0.39	0.06
10	Twyford tributary crossing	Upstream of former Great Central Main Line	84.07	0.60	0.01	84.43	0.96	0.00	84.51	1.03	0.00
11		Between existing and	83.37	0.05	-0.01	83.55	0.24	0.16	84.04	0.72	0.61

Observation point	Location	Description	Peak 5% annual exceedance probability			Peak 1% annual exceedance probability + climate change			Peak 0.1% annual exceedance probability + climate change		
			Water level (m AOD)	Flood depth (m)	Increase in afflux (m)	Water level (m AOD)	Flood depth (m)	Increase in afflux (m)	Water level (m AOD)	Flood depth (m)	Increase in afflux (m)
		proposed									
12		Downstream of Proposed Scheme	82.54	0.11	0.04	82.56	0.14	0.06	82.61	0.18	0.06

4.2.3 The results indicate that there are differing impacts as a result of the Proposed Scheme due to flow mechanisms and the location of other restrictions.

4.2.4 At Godington west the largest impact is between the proposed embankment and the existing mainline where the increase is shown to be 60mm for the 1 in 100 year plus climate change event. There is no impact upstream of the former Great Central Main Line embankment. At Godington east there is a small increase (20mm) upstream of the Proposed Scheme between the two proposed crossings. There is also a small increase between the existing and proposed crossings at Godington east as a result of the increase in water levels due to the combined impact of the double crossing.

4.2.5 For both the main crossing at Twyford and the Twyford tributary, the maximum increase in flood water level is found between the former Great Central Main Line embankment and the proposed scheme. Water levels for the 1 in 100 year plus climate change event are shown to increase by 180mm at Twyford and 160mm at the Twyford tributary. There is only a small increase (30mm) upstream of the existing embankment at Twyford.

4.2.6 A visual illustration of the flood mechanisms, flow directions and modelled flood depths as a result of the Proposed Scheme piers in the 1 in 100 years return period event (plus uplift of 20% for climate change) can be seen in Figure 10 and Figure 11, for Godington and Twyford respectively.

Figure 10: 100 year plus climate change scheme scenario flood depths (m) at Godington

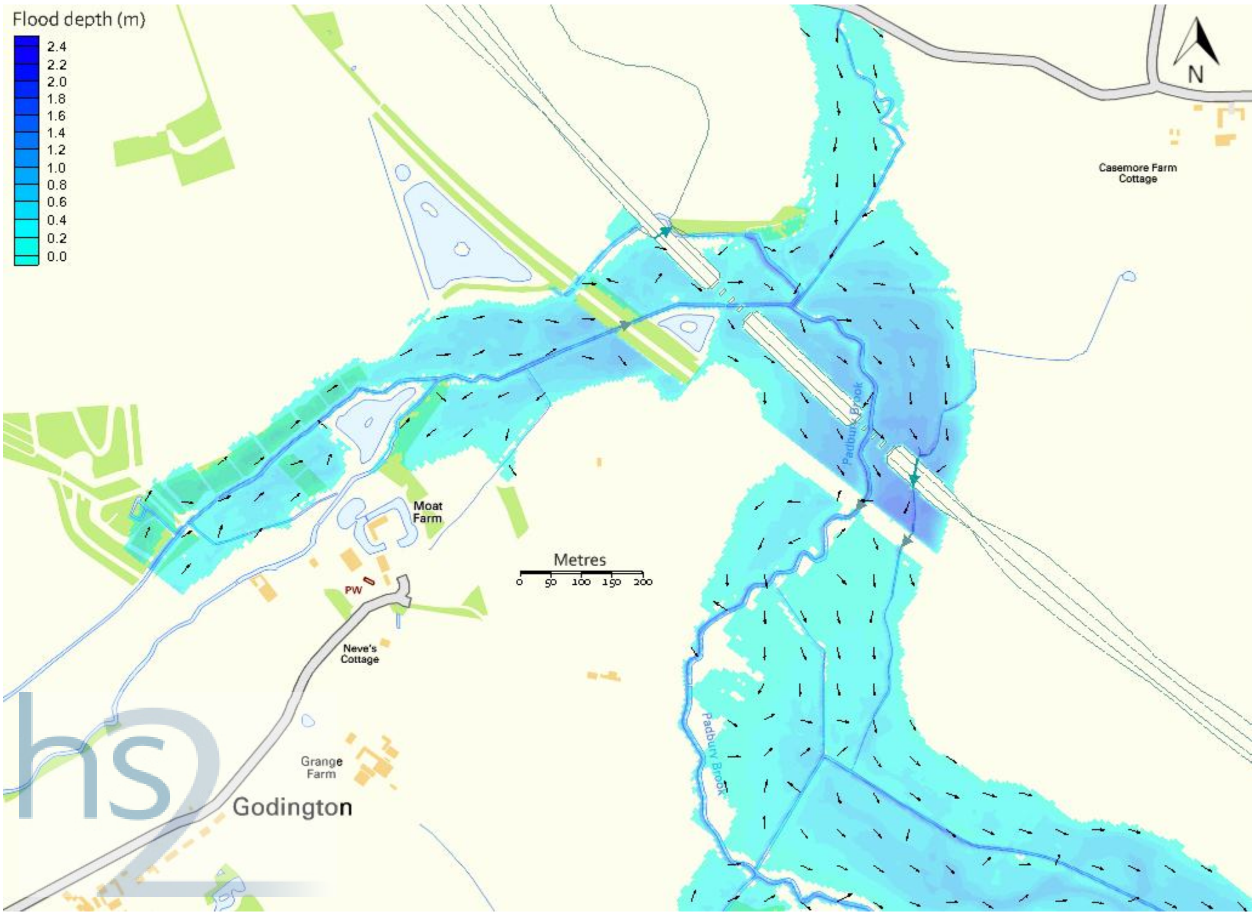
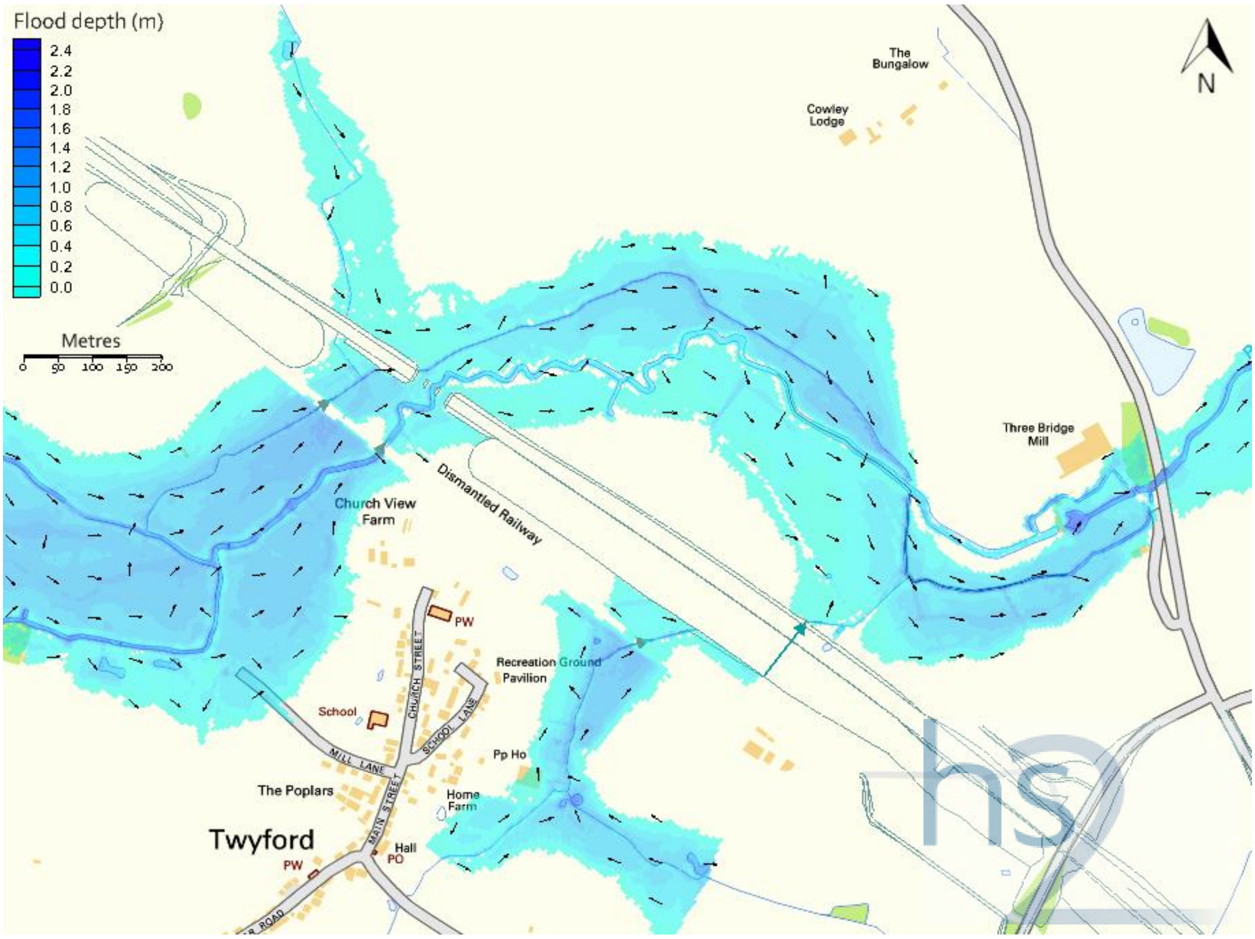


Figure 11: 100 year plus climate change scheme scenario flood depths (m) at Twyford



Flood extents

4.2.7 Outlines of floodplain extents for the 100 year plus climate change and 20 year Proposed Scheme scenarios are shown in Maps WR-05-30 and WR-06-30 respectively (Volume 5, Water Resources and Flood Risk Map Book).

4.2.8 The modelled outlines for the 1 in 100 year event (including 20% for climate change) show the following changes in extent:

- at Godington west there is a small increase in extent between the Proposed Scheme and the former Great Central Main Line embankment;
- there is a minor increase in extent between the two crossings at Godington (west and east) upstream of Godington east viaduct;
- there is an increase in extent on the right-hand side of the floodplain at Twyford between the former Great Central Main Line and the Proposed Scheme embankment. Downstream of the Proposed Scheme embankment and viaduct there is a reduction in extent on the right-hand side of the floodplain. This is due to the scheme preventing overtopping from the raised mill stream. There is also an alteration of flood mechanisms and consequently

water levels and extents on the left-hand side of the floodplain due to diversion of the tributary flow paths where it joins the Padbury Brook; and

- at the Twyford tributary there is an increase in floodplain extent, on both sides of the channel, between the existing and proposed embankments due to the encroachment of a noise bund within the floodplain. There is no change, however, upstream of the former Great Central Main Line. There is a decrease in extent on the left-hand side downstream of the Proposed Scheme due to blockage of flood flows from the tributary.

Increase in afflux

4.2.9 In order to assess the impact of the change in water levels as a result of the Proposed Scheme, further work has been undertaken to quantify the magnitude of this increase or decrease in afflux. Baseline water levels have been subtracted from the Proposed Scheme levels in order to obtain a grid of the afflux where the two results girds overlap. This was then coloured accordingly to indicate a major, moderate or minor increase or decrease in water levels in accordance with the Scope and Methodology Report (SMR) (see Volume 5: Appendix CT-001-000/1) and the SMR Addendum (see Volume 5: Appendix CT-001-000/2).

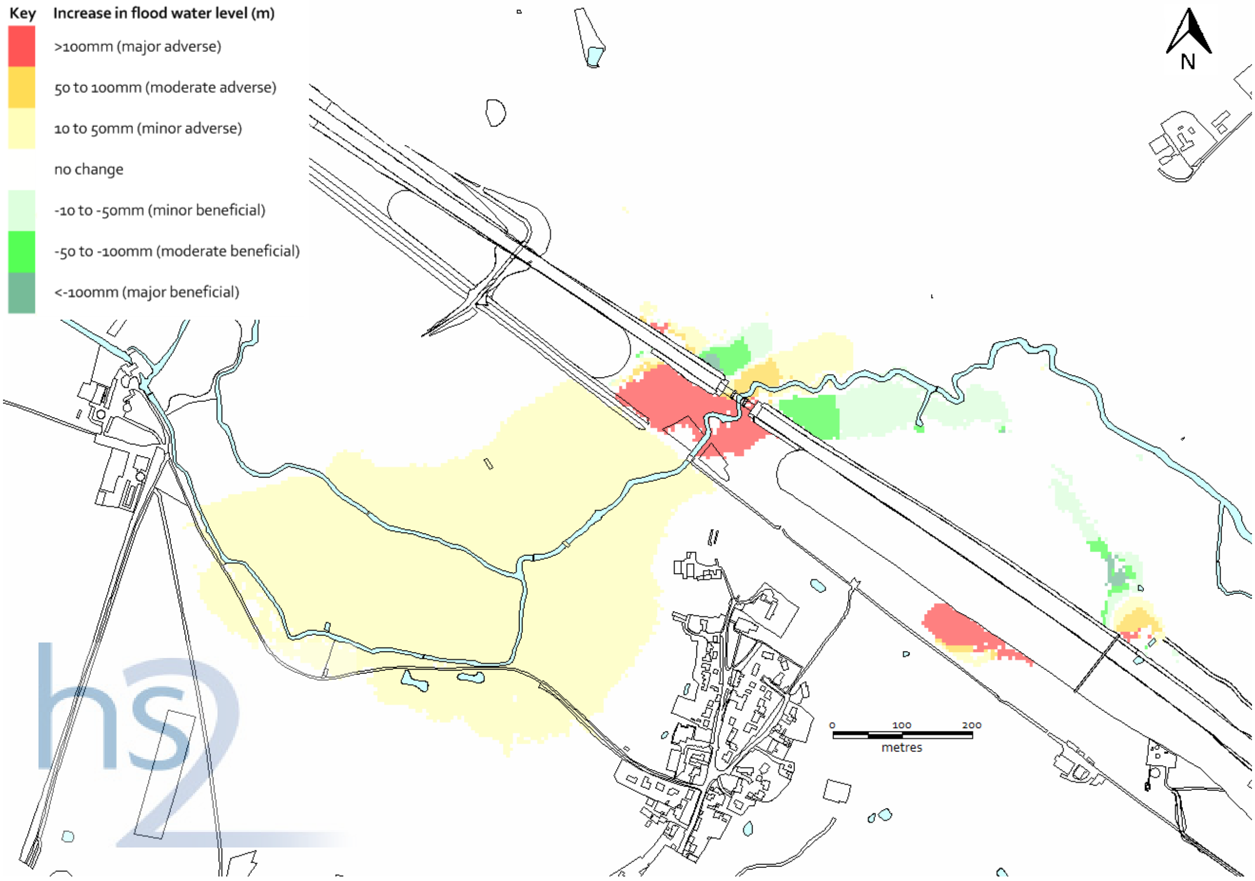
4.2.10 Figure 12 illustrates the increases in afflux as a result of the Proposed Scheme in the 1 in 100 years (1% annual probability) plus climate change event.

Figure 12: Increase in floodwater level in 100yr+cc flood event at Godington

4.2.11 There is a moderate increase upstream of Godington west between the existing and proposed embankments with a minor increase both upstream and downstream of the Godington east viaduct and embankment.

4.2.12 Figure 13 illustrates the increases in afflux as a result of the Proposed Scheme at Twyford in the 1 in 100 years (1% annual probability) plus climate change event.

Figure 13: Increase in floodwater level in 100yr+cc flood event at Twyford



4.2.13 There is a major increase in flood water level between the existing and proposed embankments at both the main crossing at Twyford and the tributary east of Twyford. There is a minor increase in afflux upstream of the former Great Central Main Line at Twyford. Downstream of the Twyford crossing blockage of flow routes over the right bank of the raised mill stream is shown to cause a decrease in the flood water level on the right-hand side of the floodplain. There is an increase on the left bank as a result.

Sensitivity testing

4.2.14 The impact of increasing the roughness of the floodplain was tested by increasing Manning's roughness values for grassland to 0.07.

4.2.15 Increasing the floodplain roughness causes an increase in flood water level across the study area which ranges from approximately 10mm to 130mm for the post development scenario. The largest increases in water level are shown between the former Great Central Main Line embankment and the Proposed Scheme.

4.2.16 The difference in afflux, when compared to the scenarios run with smoother floodplains, ranges between approximately -10mm to +30mm. This is within the expected range of variation and the choice of Manning's roughness value for the floodplain does not have a significant impact on the outcome of the modelling.

5 Conclusions

5.1.1 This modelling work was undertaken in order to quantify the impact of the Proposed Scheme at Godington and Twyford. No existing hydraulic model of the Padbury Brook was available within the study at the level of detail required for the Flood Risk Assessment (Volume 5: Appendix WR-003-013) and therefore a two-dimensional model has been constructed using SMS-TUFLOW.

5.1.2 Three main flood events have been modelled. These are the 20 year return period, the 100 year return period with an allowance of 20% for climate change, and the 1,000 year return period flood events.

5.1.3 The baseline modelling illustrates the flood mechanisms from the Padbury Brook as a result of its parallel channels, multiple inflows and the former Great Central Main Line embankment structure within the floodplain. Modelling of the Proposed Scheme scenario with embankment, viaduct piers and culverts within the floodplain shows localised changes in flood water levels.

5.1.4 Increases in water level of up to 180mm occur upstream of the Proposed Scheme embankment at Twyford and at the Twyford tributary, however, this increase is contained between the proposed structure and the existing railway embankment. There is only minimal impact upstream and a decrease in risk downstream of both the main channel and the Twyford tributary. Localised changes in floodplain extent occur as a result. At Godington, the complex combination of the two crossings in short succession and inflows from the Preston Bissett tributary cause an increase in floodwater levels on both sides of the Proposed Scheme. There is no impact upstream of the former Great Central Main Line embankment.

5.1.5 The 20cm DTM was supplemented with LiDAR on a 2m grid. A TUFLOW grid cell size of 5m was used throughout. The accuracy of the model is considered sufficient to provide the information required for this impact assessment exercise as a comparison of baseline and scheme scenarios. The model results should not be used for any purpose other than those specified in this report.

5.1.6 The purpose of this modelling exercise was to quantify the impact of the Proposed Scheme on out-of-bank water levels and extents within the Padbury Brook floodplain.

5.1.7 Baseline modelling was based solely upon information which was available at the time of this assessment. Due to limited land access, structures within this model were estimated and no topographic survey was undertaken.

6 Assumptions and limitations

6.1 General

6.1.1 This section of the report lists the key assumptions and limitations of the hydrological calculations and hydraulic modelling carried out for this study.

6.2 Hydrology

6.2.1 Flow estimation follows the guidance within the FEH in conjunction with the latest guidance on its use provided by the Environment Agency.

6.2.2 Catchment descriptors have been extracted from the FEH CD-ROM (v3) and sensibility checks have been undertaken. Where catchments have been derived by subtracting catchments the area-weighted average method has been used following guidance from Volume 5 of the FEH.

6.2.3 ReFH flows have been calculated throughout and validation or calibration of the calculated flows with gauged records has not been carried out. No statistical analysis has been undertaken for the purpose of this modelling exercise.

6.3 Use of existing models

6.3.1 No existing modelling was used.

6.4 Hydraulic modelling

6.4.1 Only the assessment of flood risk from the Padbury Brook and the relevant tributaries within the study area has been presented in this report.

6.4.2 Typically the two-dimensional grid is stable and robust once wet. The wetting process can be assisted using initial water levels, however, due to the very flat nature of the modelled area applying an initial water level creates ponding in the lower area of the model which does not drain away. Therefore, initial water levels were not utilised for the purpose of this modelling exercise.

6.4.3 The one-dimensional ESTRY components used to represent the culverts resulted in model stability issues, particularly at low flows as flow leaves the two-dimensional grid and enters the one-dimensional element. This is predominantly due to variability between the two-dimensional LiDAR elevation levels, and the upstream and downstream invert level of the culvert unit. To assist, stability flow paths in the form of 'min Z-lines' have been used in order to artificially lower a flow path a few grid cells long into the entrance and exit of the culverts. This is a standard approach for dealing with modelling instabilities of this nature.

6.5 Topography

6.5.1 No channel is cut within the ground model and therefore the in-channel level represented is actually the water level identified by the LiDAR. No modifications have been made to the ground model to reduce this level.

6.6 Model parameters

6.6.1 Infiltration losses have not been applied.

6.6.2 Roughness of the study area has been defined using broad Manning's roughness values for a selection of land use types. These were obtained from OS Mastermap data.

6.6.3 The upstream and downstream model extents have been located a sufficient distance from the crossing by the Proposed Scheme to provide sufficient length for stability.

6.6.4 Hydrological inflows have been applied in the model as point inflows.

6.7 Structures

6.7.1 No topographic survey information was available for the structures within the study area. A general walkover survey was undertaken, however, given limited or refused access the ability to measure or examine structures was not possible.

6.7.2 The size and shape of baseline structures were estimated from the limited information available using LiDAR and aerial photography. Invert levels for the culverts were estimated from the 20cm DTM LiDAR.

6.7.3 Given the importance of the existing structures within the floodplain and the influence on flood mechanisms of the Padbury Brook it is recommended that a detailed topographic survey is undertaken once land access has been made available.

6.8 Post-processing of results

6.8.1 All two-dimensional model results have been processed to a grid resolution of 5m to match the model cell size.

6.8.2 The TUFLOW flood outlines presented in this report have not undergone any post-processing such as smoothing of edges or filling in of dry islands.

6.9 Validation

6.9.1 Limited sensitivity testing of floodplain roughness has been carried out to confirm values used within the project. Further, full sensitivity analysis on all roughness parameters, structure coefficients and boundaries will be undertaken as part of detailed modelling.

6.9.2 Sensibility checks of general flood mechanisms have been undertaken based on a walkover survey undertaken in December 2012 where access was available.

7 References

Institute of Hydrology (1999), *Flood Estimation Handbook.*

Ven Te Chow (1959, 2009 edition). *Open-channel hydraulics*, The Blackburn Press, Caldwell, NJ, USA.